Pol. J. Environ. Stud. Vol. 32, No. 1 (2023), 527-533
DOI: *10.15244/pjoes/154738* ONLINE PUBLICATION DATE: 2022-12-05

Original Research

Health Risk Assessment of Benzene Using AERMOD-IRIS Method in the Vicinity of the Gas Station

Maryam Chehrehei[1], Seyed Alireza Haji Seyed Mirzahosseini[1]*, Nabiollah Mansouri[1], Mohammad Hassan Behzadi[2], Yousef Rashidi[3]

[1]Faculty of Natural Resources and Environment, Islamic Azad University, Science and Research Branch,Tehran, Iran
[2]Faculty of Basic Sciences, Islamic Azad University, Science and Research Branch, Tehran, Iran
[3]Institute of Environmental Sciences, Shahid Beheshti University, Tehran, Iran

Received: 26 May 2022
Accepted: 15 July 2022

Abstract

Exposure to benzene may adversely affect human health through non-carcinogenic and carcinogenic effects, especially leukemia. Benzene in gasoline is evaporated in the air around gas stations, and workers in gas stations are exposed to such vapors. Risk assessment is among the crucial strategies to identify and control exposure to chemicals. This study determined exposure, the non-cancer risk, and the cancer hazard of exposure of gas station workers to benzene. Benzene concentration at gas stations in Tehran was evaluated using AERMOD[1]. Cancer and non-cancer risks of benzene were then assessed by the IRIS[2] method. The highest and lowest benzene concentrations in the workers' respiratory air in the gas station were 79.47 and 9.63 μg/m^3, respectively. In the worst case, the benzene inhalation risk (IR) was 5.26 per 100000 people. The hazard quotient (HQ) of benzene was more than one (HQ>1). According to the results, the benzene-related health risk is unacceptable for most workers. Increasing and decreasing benzene's IR and HQ depend on the operating capacity and loading times of tanks in each gas station.

Keywords: benzene, cancer, gas station, risk assessment

[1] AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model

[2] IRIS: Integrated Risk Information System

*e-mail: mirzahosseini@gmail.com

Introduction

Benzene is emitted into urban air through industrial activities, especially gas stations. Benzene in gasoline is evaporated in the air around gas stations, and workers in gas stations are exposed to such vapors. Benzene volume consumed in gas stations and ambient temperature significantly increase benzene concentration [1]. Exposure to benzene may adversely affect human health through non-carcinogenic and carcinogenic effects, especially leukemia [2, 3]. Exposure to benzene may cause a wide range of adverse and harmful effects on human health during acute exposure [4-6]. Long-term inhaling a certain amount of benzene causes blood disorders in humans, including decreasing the number of red blood cells and anemia. More importantly, long-term exposure to benzene causes leukemia [7, 8]. Furthermore, inhaling high benzene concentrations for a few minutes or hours causes symptoms and signs such as sleepiness, dizziness, arrhythmia, headache and confusion [9]. The US Environmental Protection Agency (USEPA) classifies benzene in the Group A of cancer-causing materials. In addition, the International Agency for Research on Cancer introduces benzene as a cancer-causing substance for humans [10, 11].

Risk assessment is an important strategy to identify and control exposure to chemicals, including benzene. Risk assessment means detecting and determining the risk of a hazardous chemical and its potential adverse health effects of human exposure to environmental risks. Benzene emission in gas stations and an increased concern about the unfavorable health effects of these compounds have turned into a useful tool and preventive approach for regulatory objectives. Cancer (inhalation) and non-cancer (non-inhalation) risks should be assessed to protect the workforce and make decisions on controlling measures, and protect workers against the harmful effects of these compounds [12, 13]. The USEPA suggests the IRIS method for this purpose. According to the National Research Council (NRC, 1983), this method quantitatively estimates the toxicity of these substances by estimating the exposure level. In this way, cancer and non-cancer risks of benzene can be assessed [14].

According to the above discussions, risk assessment is a key tool for predicting the harmful effects of exposure to benzene. Determining the exposure of individuals to benzene is necessary to estimate its risk. There are various methods to estimate the exposure of individuals to these compounds. Air pollution dispersion models can determine benzene concentration in the ambient air. AERMOD view 8.9 is a dispersion model used in urban and non-urban areas and flat and rough surfaces. This model is used to determine the concentration of various pollutants from point, volume and surface sources [15].

Considering the health risk of benzene for operators and employees in gas stations, this study evaluates all gas stations in Tehran for the first time. Benzene emission and concentration 5 to 50 m from gas stations are modeled with the help of AERMOD, and cancer (inhalation) and non-cancer (non-inhalation) risks of benzene are assessed by the IRIS method.

Methods

Study Area

A total of 148 petrol pumps in Tehran city (Fig. 1) were studied.

Fig. 1. The place of 148 petrol pumps in Tehran.

Modeling of Benzene

To model benzene dispersion, information from 148 gas stations for the volume source of AERMOD View was entered into the software. The most important information is given in Table 1.

AERMOD consists of two parts AERMAP and AERMET. For AERMET, the raw superficial and upper air atmospheric information (8,760 hourly data) for a 1-year was taken from Iran Meteorological Organization Site (Table 2).

In order to organize and process meteorological data, first raw meteorological data in an acceptable format was entered into the software. Finally, after performing the necessary calculations on the raw files, two meteorological files with SCF and PFL extensions were obtained from the AERMET software output to enter the AERMOD distribution model.

AERMAP analyzes topographic information of the area and was designed based on USGS topographic maps. This preprocessor determines the ground height below all receivers and sources, as well as the height scale of each receiver that has the greatest impact on the distribution of pollutants in that receiver.

Using the outcomes of these two preprocessors, AERMOD performs calculations and outputs the ultimate results. Benzene concentrations were specified in a 1-year statistical period at an elevation of 1.5 m above the ground level (respiratory height), and benzene dispersion in the area was simulated.

Table 1. Parameters for the volume source.

Input for the volume source	Unit
Emission rate	g/s
Pollutant release height	m
The initial lateral dimension	m
The initial vertical dimension	m
X coordinate of source location	m
Y coordinate of source location	m
Length of side	m
Base Elevation (Source base elevation above mean sea level)	m

Table 2. Meteorological variables with two format

Variable	Raw data Format*	Format acceptable by AERMET**
Wind speed	FF	I
Wind direction	DD	H
Humidity	U	G
Temperature	t	F
Cloud cover	n	E

* Coding the raw data format from the meteorological site

** Acceptable format encoding of data in the software

Health Risk Assessment

Cancer and non-cancerous risks were calculated by the Health Risk Assessment method after modeling and determining the benzene concentration in the air around gas stations [16].

The cancer risk presented as inhalation risk (IR) is calculated from Eq. (1):

$$R = CDI \times IUR \tag{1}$$

Where:
CDI - signifies the chronic daily intake in (μg/m^3) and
IUR - is the inhalation unit risk in (μg/m^3)$^{-1}$ obtained from the software.

CDI air-inhalation- cancer is calculated from Eq. (2):

$$CDI\ air - inhalation - ca = \frac{C \times EF \times ED \times ET}{AT \times LT} \tag{2}$$

The non-cancer hazard is uttered in the form of the hazard quotient (HQ). The HQ was calculated from Eq. (3):

$$HQ = CDI / RFC \tag{3}$$

Where:
CDI - signifies the chronic daily intake in (μg/m^3), and
RFC - (Reference Concentration) is the non-cancer coefficient in (mg/m^3) obtained from the software.

CDI air-inhalation- non-cancer is calculated from Eq. (4):

$$CDI\ air - inhalation - nca = \frac{C \times EF \times ED \times ET}{AT \times ED} \tag{4}$$

The hazards were computed according to the recommended reference doses and working conditions of the studied petrol stations workers (Table 3).

The inverse distance weighting (IDW) method in Geographic Information System (GIS) software was used to prepare zoning maps for health and cancer risk assessment. In this method, the distances of known points from a specific point are calculated according to the defined latitude and longitude, and by considering the numerical values of known points entered in the program, the numerical value of the total points of the page as output.

Results and Discussion

The concentration of benzene around the gas stations was predicted using AERMOD software. The minimum and maximum emission rates of benzene

Table 3. Description of the variables used in calculating non-cancer and cancer hazards [17].

Variable	Description	Value	Unit
C	Contaminant concentration in Air	-	µg/m^3
AT	Averaging time- outdoor worker	365	day
ED	Exposure duration - outdoor worker	25	y
EF	Exposure frequency - outdoor worker	365	day/y
ET	Exposure time - outdoor worker	8	h
LT	Lifetime	70	y

Table 4. Cancer (inhalation unit risk) and non-cancer (reference concentration) coefficients.

Chemical	IUR* (µg/m^3)$^{-1}$	IUR (Reference)	RFC*** (mg/m^3)	RFC (Reference)
Benzene	7.8×10^{-6}	IRIS**	3×10^{-2}	IRIS

* IUR: Inhalation unit risk
** IRIS: Integrated Risk Information System
*** RFC: Reference Concentration

are respectively about 9.63 µg/m^3 and 79.47 µg/m^3 in the air around the gas station.

Cancer and non-cancer risks were calculated by the risk assessment method after modeling and determining the benzene concentration in the gas station air. The chronic daily intake (CDI) was calculated from the above equations for 8 h exposure to benzene concentration in 260 working days and 25 working years in 70 years [18].

The inhalation risk (IR) and hazard quotient (HQ) were obtained considering a cancer coefficient of 7.8×10^{-6} and a non-cancer coefficient of 3×10^{-2} that the software calculates (Table 4).

Table 5 reports the maximum and minimum non-cancer and cancer risks of exposure to benzene at petrol stations in Tehran. The highest exposure of workers to benzene is about 79.47 µg/m^3. The approximate cancer risk (IR) of benzene is 5.26×10^{-5}. The non-cancer risk and health hazards of benzene are about 6.29×10^{-1}. The lowest exposure to benzene is 9.63 µg/m^3. The cancer risk of benzene is 6.37×10^{-6}. The non-cancer health risk of benzene is about 7.62×10^{-2}.

Based on the location of gas stations and the IDW method, Fig. 2 shows the IR zoning map, and Fig. 3 shows the HQ map. Gas station number 147 has a high risk of cancer and health.

Table 5. Cancer and non-cancer risks of lowest and highest exposure to benzene in Tehran gas stations.

Benzene concentration µg/m^3	Non-cancer risk assessment HQ*	Cancer risk assessment IR**
79.47	6.29×10^{-1}	5.26×10^{-5}
9.63	7.62×10^{-2}	6.37×10^{-6}

* HQ: Hazard quotient
** IR: Inhalation risk

In a study conducted in Rio de Janeiro, the obtained BTEX concentrations were lower than those in petrol stations from other countries because the Brazilian petrol is mixed with 27% v/v of anhydrous ethanol, changing the volatility BTEX and reducing emissions of these pollutants to the air [19]. The risk of benzene in the atmosphere around petrol stations of District 1, Tehran, was studied in 2013. The results showed a significant increase in cancer risk [20]. Investigators studied the health risk of BTEX compounds at Mashhad gas stations. According to their results, gas station workers are exposed to high levels of volatile gasoline compounds [21]. Researchers evaluated the health risk of benzene at petrol stations in Khon Kaen, Thailand. According to the results, most workers had experienced adverse symptoms related to benzene venomousness [22]. A study entitled "assessment of BTEX concentrations in air ambient of gas stations and the health risks for workers" was conducted in 2017. The cancer hazard was very high because the values found were 40-378 times above the acceptable limit [23]. Investigators conducted a study entitled "risk assessment on benzene exposure among gasoline station workers". Inhalation exposure risk was assessed using the USEPA index, indicating a high risk of harmful health effects in 51.33% of workers [24]. Researchers studied the cancer risk of benzene in US gas stations. Based on the risk valuation results, cancer risks from benzene exposures due to fuel pumping were low for both customers and workers [25].

Comparing the benzene concentration and cancer and non-cancer risks obtained in this study with other cities in Iran and the world, the values found for benzene and its risk assessment were generally higher

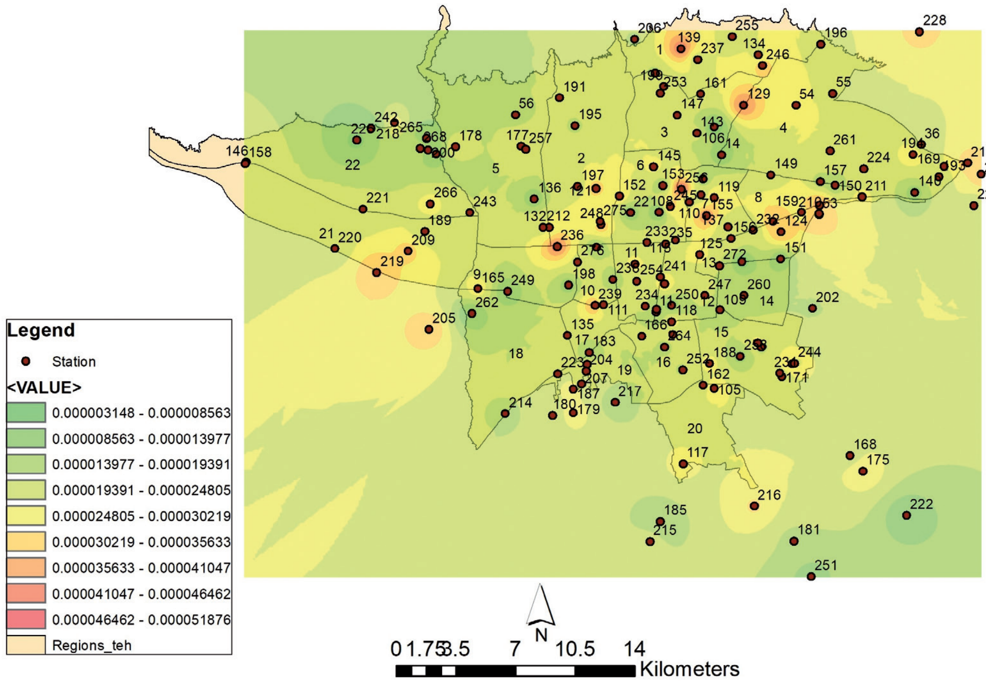

Fig. 2. IR zoning map with IDW method.

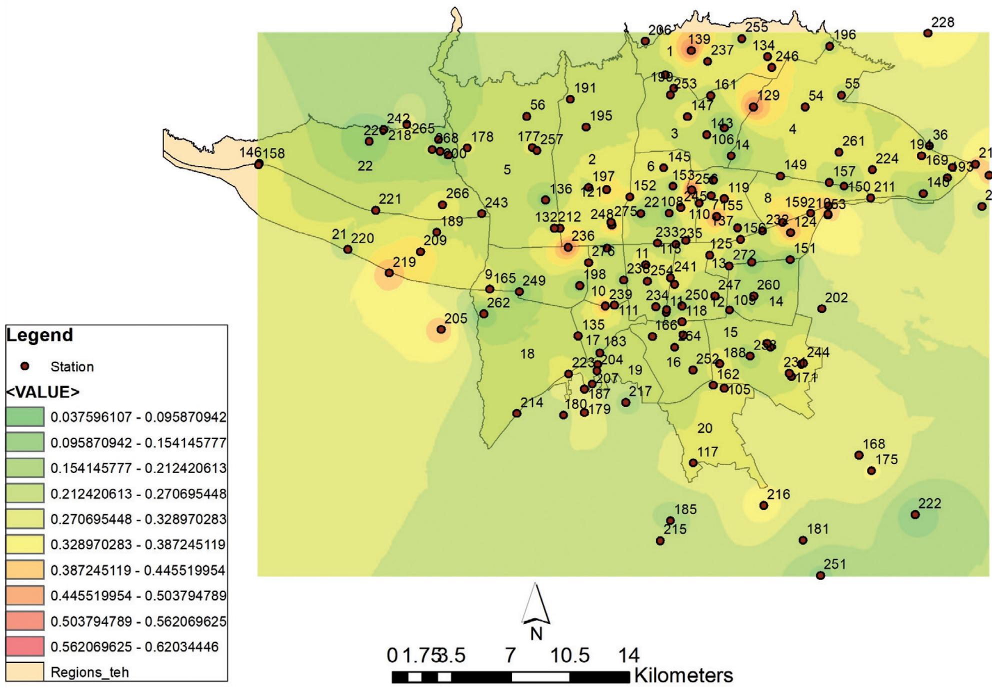

Fig. 3. HQ zoning map with IDW method.

than obtained values. These variations can be attributed to differences in the composition of the fuels used in other countries, the influence of seasonal and, or weather local factors, geographical and topographical factors, and climate factors such as wind, rain, fog, inversion, air stability, residual pollutants in the city, green space shortage, and increased population.

Based on standards announced by the World Health Organization (WHO) and USEPA, there is no significant adverse health effect when the non-cancer risk index (HQ) is less than unity (HQ<1). In contrast, there is a risk of non-cancer and health effects when HQ>1. Assessing the non-cancer risk of exposure to benzene at gas stations in Tehran showed that HQ>1, indicating the risk of non-cancer and health effects in gas station workers. The cancer risk larger than and less than 10^{-6} is considered with cancerous effects and acceptable, respectively. The results of this study demonstrated that the health risks associated with exposure to benzene in most workers were unacceptable.

This study evaluated all gas stations in Tehran for the first time. Increasing and decreasing cancer and non-cancer risks of benzene are dependent on factors affecting the emission of vapors, such as the operating capacity and the number of times the tanks are filled and emptied in each gas station. The cancer risk increased by increasing the storage capacity of tanks and the number of annual loading times. The cancer risk decreased by decreasing the storage capacity of tanks and the number of annual loading times.

Conclusions

Benzene is an important pollutant usually found in indoor and outdoor spaces, attracting the attention of many researchers worldwide. Benzene is emitted during gasoline burning in vehicles and vapors from gas stations. Accordingly, gas station personnel are constantly exposed to this dangerous chemical. Benzene is known as one of the most hazardous chemicals in the work environment, necessitating assessing the exposure of gas station workers to this harmful pollutant. The results showed that the cancer hazards are very high in all filling stations, highlighting the need to adopt measures to decrease these risks through the obligatory use of protective equipment by workers, accompanied by oversight by agencies responsible for protecting them from exposure to benzene. Benzene vapor emission and cancer risks increased in gas stations where there is high demand for fueling, and the number of loading storage tanks (charge and discharge) and the storage capacity of tanks are high. Further gas stations can be constructed to sell gasoline and disperse benzene in the region, not accumulate in a gas station and a specific area to decrease the benzene concentration and prevent its accumulation in particular points.

Finally, control measures such as installing the vapor recovery system and implementing the KAHAB Plan (Reduction, Transfer, and Recovery of gasoline vapors) and proper maintenance of fuel distribution equipment and the use of clean fuels are recommended to reduce exposure risk to such compounds significantly. Moreover, benzene concentration should be reduced in the gasoline production process in refineries.

Acknowledgments

The authors would like to express their gratitude to the Meteorological Organization of Iran for providing us with the meteorological data that were used in this research.

Conflict of Interest

The authors declare no conflict of interest.

References

1. PERIAGO J., ZAMBUDIO A., PRADO C. Evaluation of environmental levels of aromatic hydrocarbons in gasoline service stations by gas chromatography. Journal of Chromatography A. 778 (1), 263, **1997**.
2. OKONKWO C., EHILEBOH A., NWOBODO E., DIKE C. The effects of acute gasoline vapor inhalation on some hematological indices of albino Wistar rats. J. Acute Dis. **5** (2), 123, **2016**.
3. OWAGBORIAYE F., DEDEKE G., ASHIDI J., ALADESIDA A., OLOOTO W. Hepatotoxicity and genotoxicity of gasoline fumes in albino rats. Beni-Suef univ. j. basic appl. sci. **6** (3), 253, **2017**.
4. FONTES T., BARROS N., MANSO M. Human health risk due to urban petrol stations, International Conference on Urban Risks, Lisboa; **2016**.
5. HEYDARI M., OMIDVARI M., FAM I.M. Presenting of a material exposure health risk assessment model in Oil and Gas Industries (case study: Pars Economic and Energy Region). Saf Health Work. **3** (4), 11, **2014**.
6. HU R., LIU G., ZHANG H., XUE H., WANG X. Levels, characteristics and health risk assessment of VOCs in different functional zones of Hefei. Ecotoxicol. Environ. Saf. **160**, 301, **2018**.
7. WALSER T., JURASKE R., DEMOU E., HELLWEG S. Indoor exposure to toluene from printed matter matters: complementary views from life cycle assessment and risk assessment. Environ. Sci. Technol. **48** (1), 689, **2014**.
8. NEGHAB M., HOSSEINZADEH K., HASSANZADEH J. Early Liver and Kidney Dysfunction Associated with Occupational Exposure to Sub-Threshold Limit Value Levels of Benzene, Toluene, and Xylenes in Unleaded Petrol. Saf Health Work. **6** (4), 312, **2015**.
9. MAFFEI F., HRELIA P., ANGELINI S., CARBONE F., FORTI G., BARBIERI A., SANGUINETTI G., MATTIOLI S., VIOLANTE F. Effects of environmental benzene: Micronucleus frequencies and hematological values in traffic police working in an urban area. Mutat Res Genet Toxicol Environ Mutagen. **583** (1), 1, **2005**.
10. LOPRIENO N. International Agency for Research on Cancer (IARC) monographs on the evaluation of carcinogenic risk of chemicals to man: "Relevance of data on mutagenicity". Mutat Res Genet Toxicol Environ Mutagen. **31** (3), 201, **1975**.
11. VLAANDEREN J., LAN Q., KROMHOUT H., ROTHMAN N., VERMEULEN R. Occupational benzene exposure and the risk of lymphoma subtypes: a meta-analysis of cohort studies incorporating three study quality dimensions. Environ. Health Perspect. **119** (2), 159, **2011**.
12. SAHRANAVARD Y., ZARE S., KALANTARY S., OMIDI L., KARAMI M. Determining Benzene, Toluene, Ethylbenzene and Xylenes (BTEX) Concentrations in the Hydrometallurgical Environment of Sarcheshmeh Copper Complex, JOHE. **2** (4), 9, **2016**.
13. JAHANI A. Sycamore failure hazard classification model (SFHCM): an environmental decision support system (EDSS) in urban green spaces. Int J Environ Sci Technol. **16** (2), 955, **2019**.
14. National Research Council (NRC). Review of EPA's integrated risk information system (IRIS) process. National Academies Press, **2014**.
15. User's Guide for the AMS/EPA Regulatory Model (AERMOD). Office of Air Quality Planning and Standards Air Quality Assessment Division Air Quality Modeling

Group Research Triangle Park, North Carolina. EPA-454/B-18001. **2018**.
16. Risk Assessment Guidance for superfund, Volume I: Human Health Evaluation Manual (Part A). Washington DC. **1989**.
17. The Risk Assessment Information System, RAIS Chemical Risk Calculator, **2020**.
18. TUNSARINGKARN T., PRUEKSASIT T., KITWATTANAVONG M., SIRIWONG W., SEMATONG S., ZAPUANG K., RUNGSIYOTHIN A. Cancer risk analysis of benzene, formaldehyde and acetaldehyde on gasoline station workers. Journal of environmental engineering & ecological science. **1** (1), 1, **2012**.
19. CORREA S., ARBILLA G., MARQUES M., OLIVEIRA K. The impact of BTEX emissions from gas stations into the atmosphere. Atmospheric Pollut. Res. **3** (2), 163, **2012**.
20. ATABI F., MIRZAHOSSEINI S. GIS-based assessment of cancer risk due to benzene in Tehran ambient air. Int J Occup Med Environ Health. **26** (5), 770, **2013**.
21. JALALI M., JALALI S., SHAFIEE MOTLAGH M., MARDI H., NEGAHBAN S., FARAJI TOMARKANDI V., JAHANGIRI M. Health Risk Assessment of Occupational Exposure to BTEX Compounds of Gasoline Fuel Distribution Stations in Mashhad. Journal of Neyshabur University of Medical Sciences. **1** (1), 19, **2014**.
22. CHAIKLIENG S., PIMPASAENG C., THAPPHASARAPHONG S. Benzene Exposure at Gasoline Stations: Health Risk Assessment. Hum Ecol Risk Assess. **21** (8), 2213, **2015**.
23. CRUZ L., ALVE L., SANTOS A., ESTEVES M., GOMES Í., NUNES L. Assessment of BTEX Concentrations in Air Ambient of Gas Stations Using Passive Sampling and the Health Risks for Workers. J Environ Prot. **8** (1), 12, **2017**.
24. CHAIKLIENG S., SUGGARAVETSIRI P., AUTRUP H. Risk Assessment on Benzene Exposure among Gasoline Station Workers. Int J Environ Res Public Health. **16** (14), 2545, **2019**.
25. PATTON A., LEVY-ZAMORA M., FOX M., KOEHLER K. Benzene Exposure and Cancer Risk from Commercial Gasoline Station Fueling Events Using a Novel Self-Sampling Protocol. Int. J. Environ. Res. Public Health. **18** (4), 1872, **2021**.